SOME RESULTS OF THE JOVIAN DAM EMISSION INVESTIGATION WITH WAVELET ANALYSIS TECHNIQUE

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Abstract

The Jovian decameter radio emission (the fundamental millisecond S–bursts) has been investigated with the wavelet transform technique relatively recently developed for signal processing. The data taken for analysis has been observed with an acousto–optical spectrograph designed at the Observatory Nançay, and installed into the world–largest decameter band radio telescope UTR–2 (Kharkov, Ukraine) within the frame of a joint Ukraine–France–Austria research project. The consideration of the wavelet spectrum obtained with the continuous wavelet transformation (CWT) has been carried out for the separate S–burst events and for the long–duration time series in the different frequency channels. With the technique of the discrete wavelet transformation (DWT) the presence of the clearly expressed flicker–noise component in the studied signals has been found. The spectral parameter γ characterizing such processes has been calculated for the different frequency events. Preliminary analysis showed that the oscillations of the different scales, containing the signal, have a similar behavior throughout the frequency band, which is approximately equal to 180–200 kHz. This result allows us to conclude that the radiation in the source has this instantaneous frequency band, and the observed frequency shift in the band is caused by the further signal propagation.

1 Introduction

Jovian decametric S–bursts represent an "exotic" component of the Jovian radiation and its generation scenario and specific properties have been much debated for years [Flagg and Desch, 1979; Carr and Reyes, 1999; Goertz, 1976; Genova and Leblanc, 1981; Imai

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et al., 1997; Litvinenko et al., 1999; Litvinenko et al., 2000; Rucker et al., 2000; Ryabov, 1992]. S–bursts manifest themselves as a series of short pulses with durations from a few to tens of milliseconds and are strongly controlled by the satellite Io, i.e. they are detected only in two particular configurations of the Io–Jupiter–observer angle. S–bursts occupy approximately 10% of occurrence probability of the total decameter emission of Jupiter. One of the most interesting properties of S–bursts is their rapid drift in the frequency–time plane, which is not yet clear explained [Ryabov and Gerasimova, 1990 and references therein]. For instance, using a model of an adiabatic motion of electrons trapped in the Io flux tube and emitted at the gyrofrequency (mechanism of electron–maser instability) is insufficient to explain the instantaneous drift rate of an individual structure [Rucker et al., 2000; Boev and Shcherbinina, 2000].

Investigation of the "fine" temporal and frequency structure of the Jovian decameter emission is the problem and its solution is potentially capable of developing a detailed radiation mechanism which describes a maximum number of the observed parameters. In this work we have been considered the "fine" structure of the millisecond Jovian S–bursts with the wavelet analysis method. Some results obtained by visual wavelet spectra analysis and proved by the spectral parameter calculations for the set of S–bursts in the different frequency channels will be discussed.

2 Wavelet analysis method

The wavelet transform is a mathematical technique enabling the division of data, functions or operators into different frequency components and then considers each component with a resolution matched to its scale. Wavelet transform yields a time–frequency description similar to the windowed Fourier transform, but with an important difference consisting in the shapes of the analyzing functions [Daubechies, 1988]. In the Fourier transform all the used window functions have the same envelope function "filled in" with higher frequency oscillations. All the window functions, regardless of the frequency value, have the same width. Contrary to that, the wavelets have time–widths adapted to their frequency: wavelets of high frequency are very narrow, while wavelets of low frequency are much broader. Wavelet transform is able to "zoom in" on very short–lived high frequency phenomena, such as, for instance, local periodicity or non–stationarities in the signals.

For a one–dimensional signal $s(t)$ the wavelet transformation consists in their decomposition on an orthonormal basis of functional Hilbert space being produced from a mother–wavelet $\Psi(t)$ (soliton–similar function) by scale transformations and shifts. So the wavelet transform performs a very simple time–frequency description of the signal with wavelet coefficients $s_n^m(t)$ which are the projections of $s(t)$ function to a full orthonormal basis in functional Hilbert space $\mathrm{L}_2(\mathrm{R})$:

$$s(t) = \sum_m \sum_n s_n^m \psi_n^m(t). \tag{1}$$

$$\psi_n^m(t) = 2^{m/2}\Psi(2^m t - n), \qquad m, n \in \{\ldots, -2, -1, 0, 1, 2, \ldots\}. \tag{2}$$

In equations (1) and (2) m is the scale index and n is the translation index. This way the wavelet coefficients $s_n^m(t)$ of the $s(t)$ signal are the projections of the $s(t)$ function to a full orthonormal basis $\psi_n^m(t)$ in $L_2(R)$.

Wavelet transform exists in two main types: the continuous wavelet transform (CWT) and the discrete wavelet transform (DWT). In the CWT the dilation and translation parameters m and n vary continuously over $L_2(R)$. In the DWT both parameters take only discrete values.

In the last ten years wavelets have been successfully applied in many areas of signal processing [Mallat and Hwang, 1992; Wilson et al., 1992]. One major difference between most applications of wavelets is the choice of the mother wavelet. In our work for the orthogonal basis forming the complex Morlet wavelet with the limited definition field was chosen as the basis mother wavelet function, which seems to be the best fit for our investigations.

3 Wavelet spectra consideration

For our purpose to analyze the superfine structure of the Jovian S–bursts we choose the signals in the frequency channels from 19 MHz to 19.8 MHz (at 30 kHz steps) and with 0.5 s time duration (see marked part in Figure 1). Applying to these signals an algorithm of the wavelet spectra numerical calculation, based on the continuous wavelet transform technique, we get the set of the wavelet spectra images. By visual analysis we noted the following intriguing fact that the bursts are drifting with main frequency changing, but the internal frequency content and spectra behavior versus time are stable over approximately 200 kHz. As an example, in Figure 2 the signal variations versus time and respective wavelet spectra of the events in frequency band 19–19.18 MHz are shown.

It can also clearly be seen that the considered signals have a periodic (harmonic) structure with a frequency approximately equal 22 Hz.

4 Spectral parameter γ for the investigated events

It was shown [Litvinenko et al., 2000] that the Jovian decameter radiation contains a clearly expressed flicker–noise component (1/f component) whose empirical power spectrum is of the form

$$P(\omega) \approx \frac{\sigma_s^2}{|\omega|^\gamma} \tag{3}$$

where γ is the spectral parameter in the range $0 < \gamma < 2$ and typically $\gamma \approx 1$, ω is the circle frequency, and σ_s^2 is the standard deviation of the signal.

With an algorithm developed by Wornell and Oppenheim [1992] we analyzed the Jovian temporal signal variations in the separate frequency channels mentioned above. The

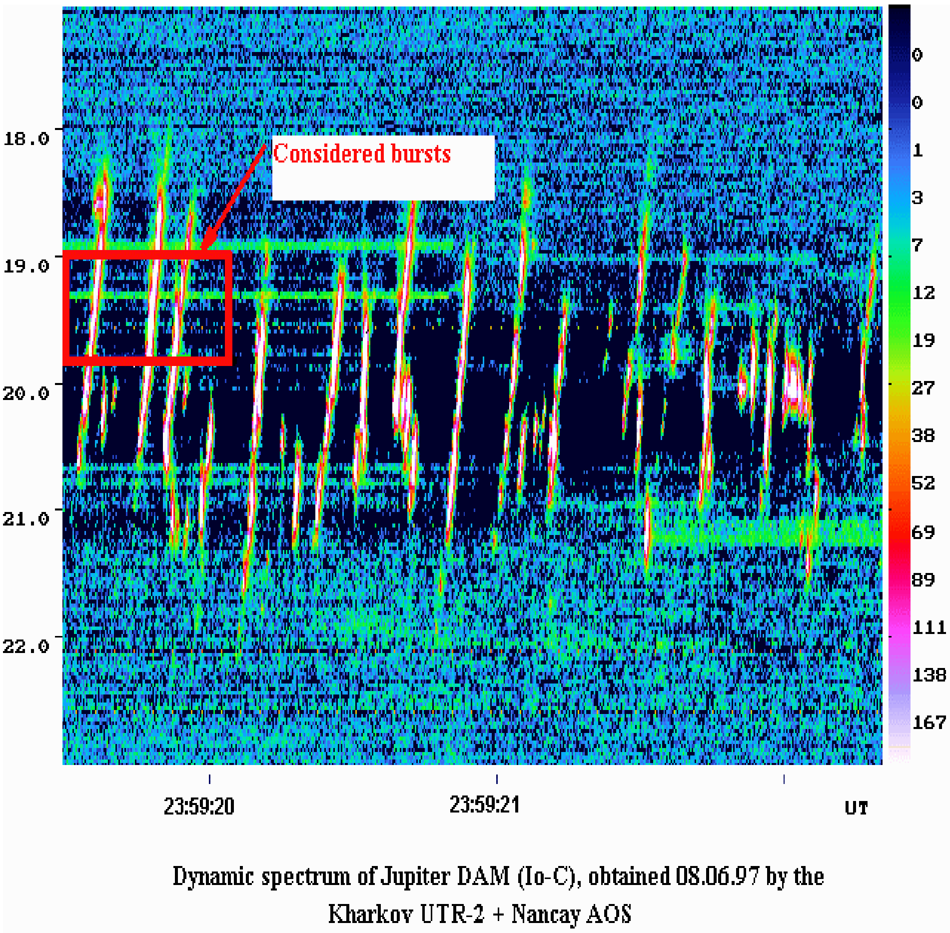

Figure 1: Dynamic spectrum of the Jovian decametric S–bursts.

indicated procedure is based on a maximization of a likelihood function for the wavelet coefficients $s_n^m(t)$, obtained for the initial data set $s(t)$ with the discrete transform technique. The studied signal $s(t)$ was considered as a superposition of two statistically independent processes, a flicker–noise and a white Gaussian noise:

$$s(t) = f(t) + w(t) \tag{4}$$

where $f(t)$ is the flicker–noise component, $w(t)$ is the white Gaussian noise component.

The main parameter we have extracted from experimental data is the spectral parameter γ.

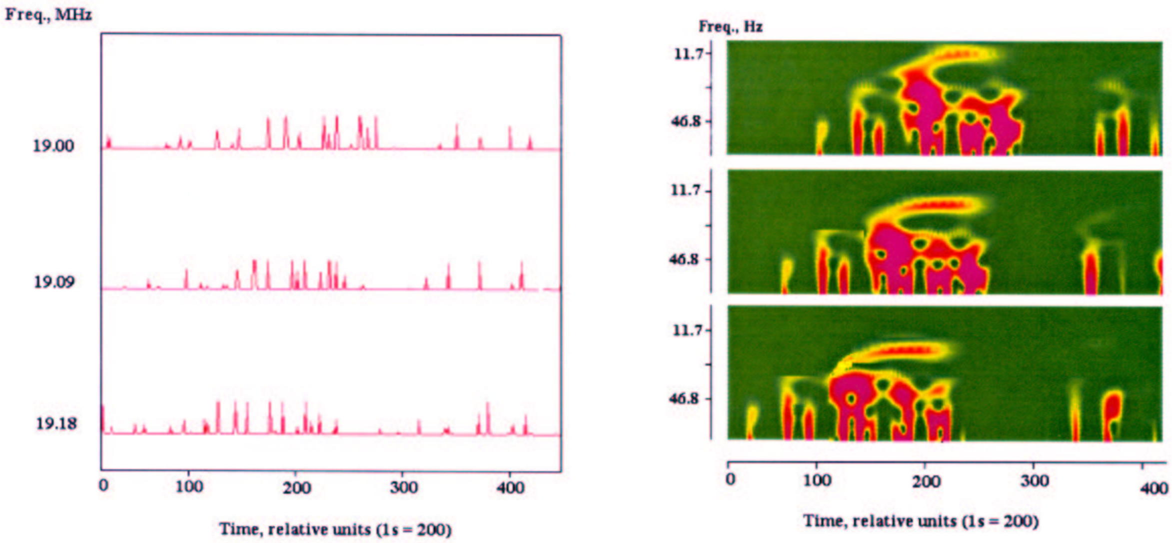

Figure 2: The signal variations versus time and respective wavelet spectra of the events in frequency band 19–19.18 MHz.

Frequency band (MHz)	Spectral parameter γ	Pulse duration τ (s)
19.00 – 19.18	0.9	0.001
19.21 – 19.39	1.2	0.003
19.42 – 19.60	2.0	0.02

In Table 1 examples of the spectral parameter γ calculation have been shown. It can be seen that the frequency intervals of the stable value of γ (19–19.18 MHz, 19.21–19.39 MHz and so on) are similar to that we have marked above from the wavelet spectra analysis.

4.1 Discussion

The results obtained with the wavelet analysis technique of the Jovian S–bursts superfine structure investigation allow us to suppose that the source region of the Jupiter decameter radiation has an instantaneous frequency band emission of about 200 kHz. It means that an excitation increment of instability which is a cause of the decameter S–bursts generation has a narrow frequency band $\triangle f/f \approx 10^{-4}$. This instability has a periodic character with a time scale about 50 ms.

A model for Io phase dependent S–bursts in Jupiter decameter radio emission, which is able to explain the obtained results, was proposed in Zaitsev et al.,[1986]. In this work the source region was considered as a multi–component system composed of an equilibrium plasma and an admixture of loss–cone ions and electrons. The loss–cone electrons excite plasma waves in the band $\triangle\omega/\omega \leq \omega_P^2\omega_B^2$ (ω_P is the plasma frequency, ω_B is the electron gyrofrequency) near the upper–hybrid frequency. The plasma waves convert, because of induced scattering by thermal and loss–cone ions, into an extraordinary electromagnetic wave with a refractive index less than 1, which ensures that the radio emission is amplified to the observed level. Different types of plasma wave conversion into electromagnetic waves lead to the quasi–periodic character of S–bursts. In this model the frequency drift can be explained by the group delay of extraordinary waves during first their propagation in the region with low refractive index and second the wave propagation from the source to the observer.

Of course, these results need to be supported by statistical investigations. As future work we plan to process an amount of different S–burst events with the aim to get more stable and detailed information.

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